Multi-baryonic Λ_b^0 Decays

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FSP meeting

Bochum

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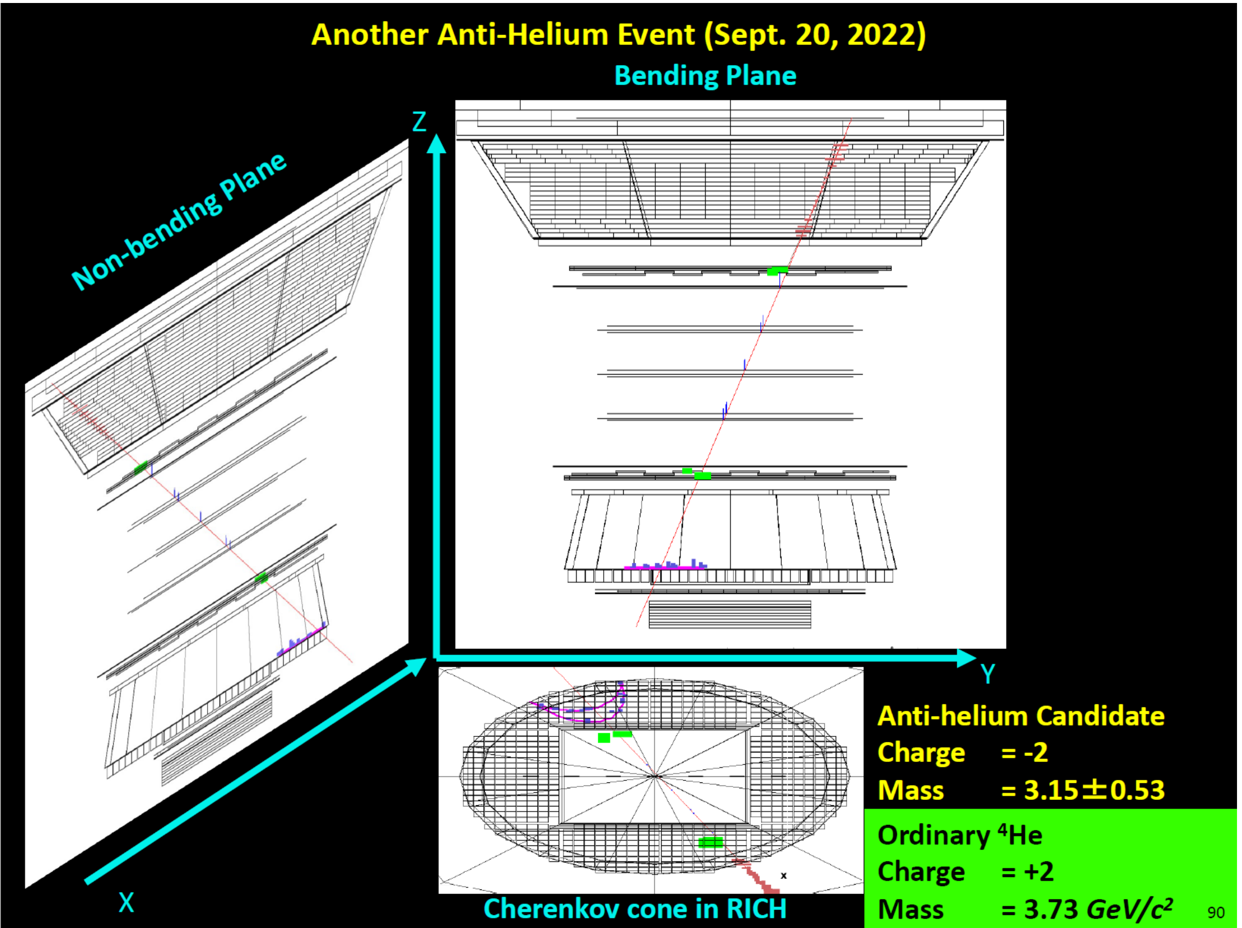
$\overline{\mathrm{He}}$ production in $\bar{\Lambda}_b^0$ decays

Several $\overline{\mathrm{He}}$ candidates of unknown origin have been reported by the AMS-02 experiment

S. Ting CERN colloquium



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Dark Matter Annihilation Can Produce a Detectable Antihelium Flux through $\bar{\Lambda}_b$ Decays

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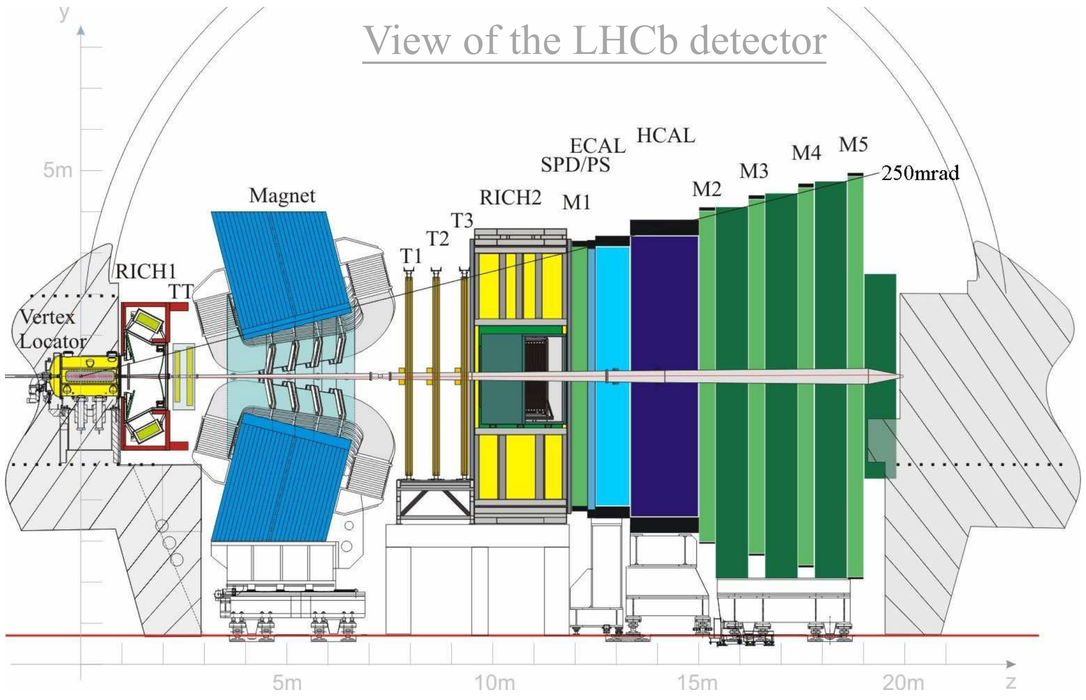
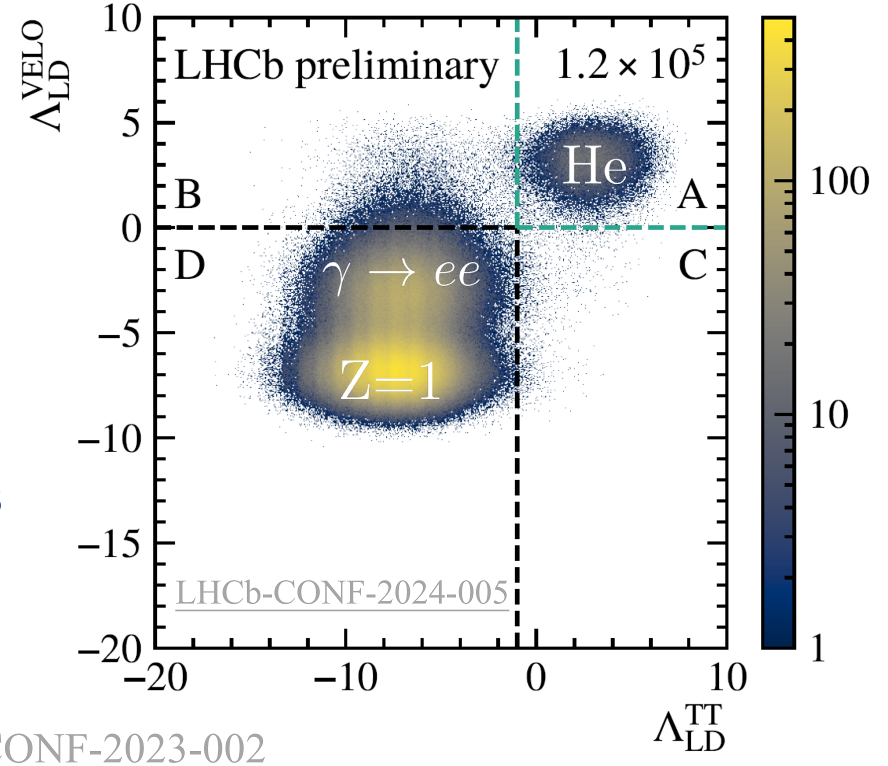
View of the LHCb detector



- LHCb ideal for studying Λ_b^0 decays
- No helium identification in LHCb before
- ✓ Developed by the RWTH Aachen group in Run 2

Helium identification

- Use energy-loss information in VELO, TT, and IT
- Further separation from RICH, isolation, calorimeters and OT information
- Achieve excellent separation between helium and Z=1 particles
- Validated in the antihypertriton analysis



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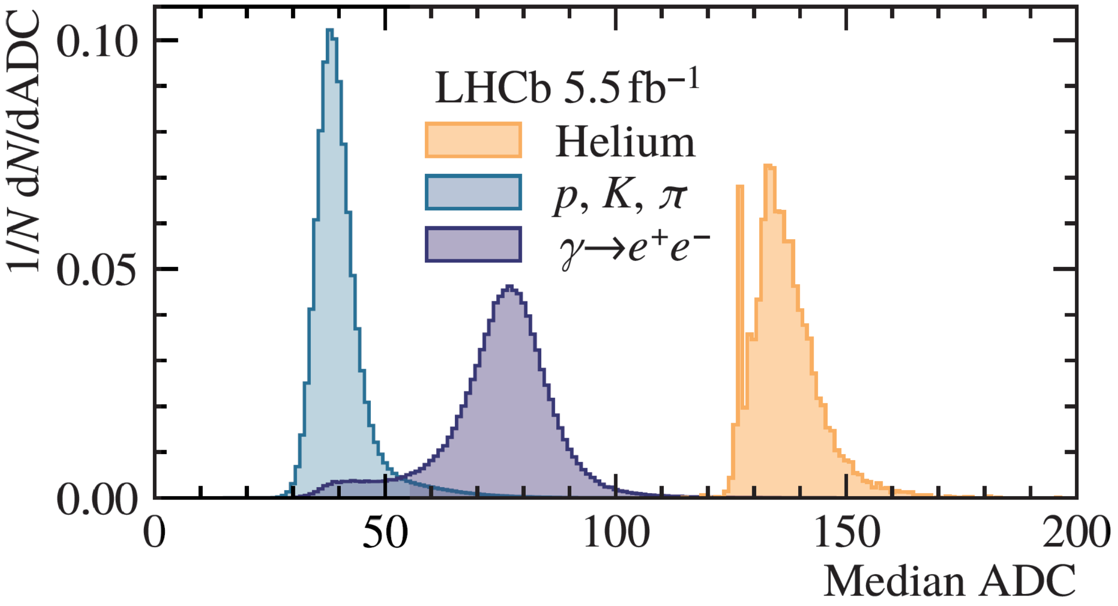

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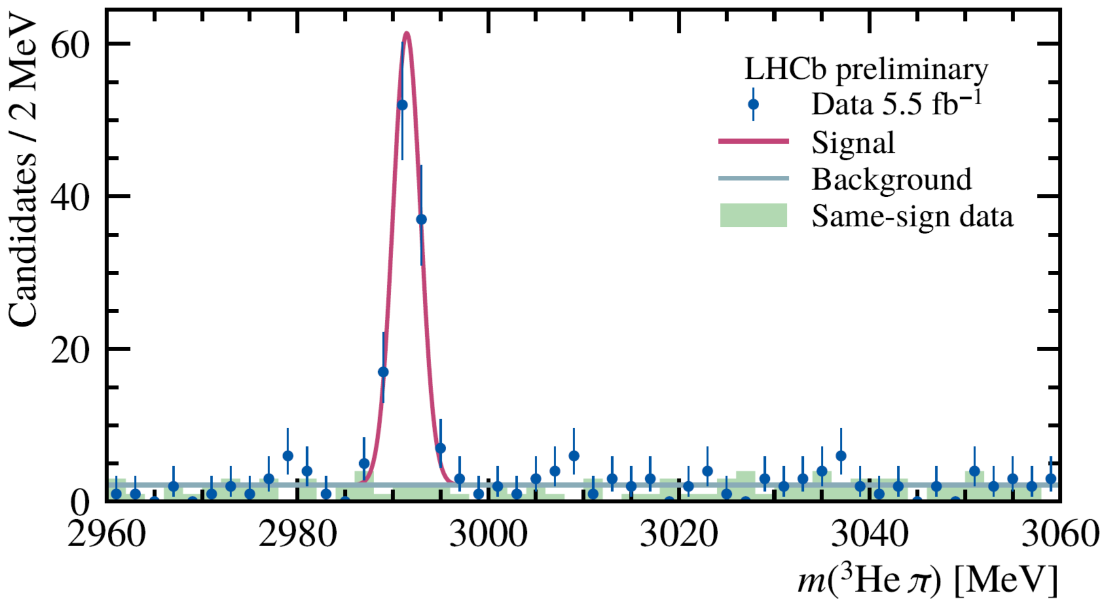
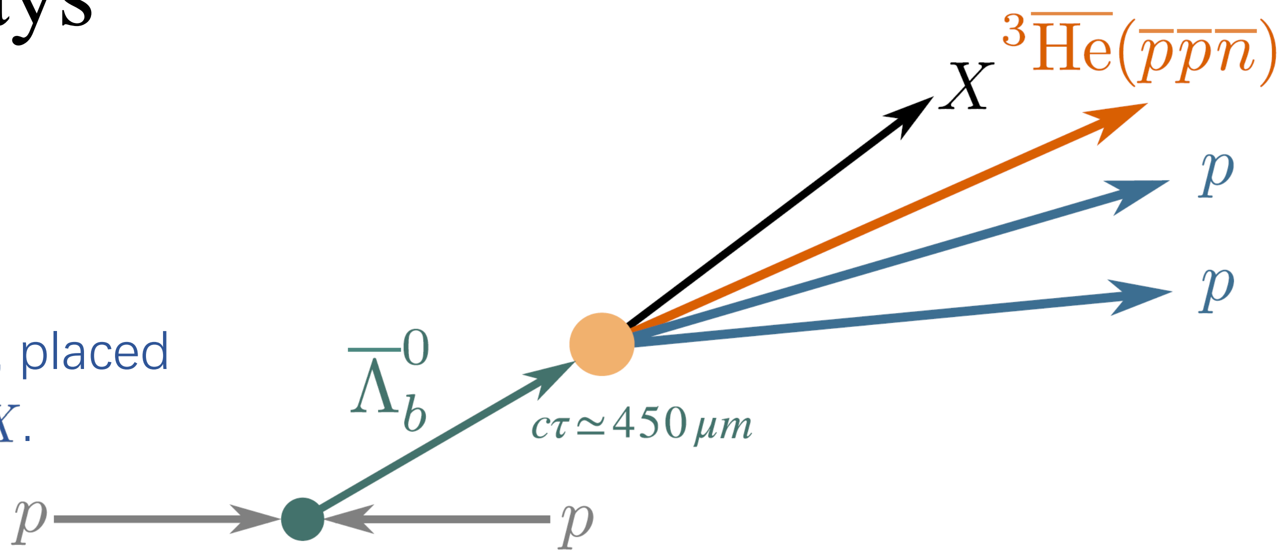


Anti-helium BF in $\bar{\Lambda}_b^0$ decays

- Analysed:
  1. $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}$ (exclusive)
  2. $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X$ and $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}X$ (inclusive)
- Extrapolating from the $\Lambda_b^0 \to {}^3\mathrm{He}\overline{p}\overline{p}X$ mode, placed an upper limit on inclusive mode $\Lambda_b^0 \to {}^3\mathrm{He}X$.



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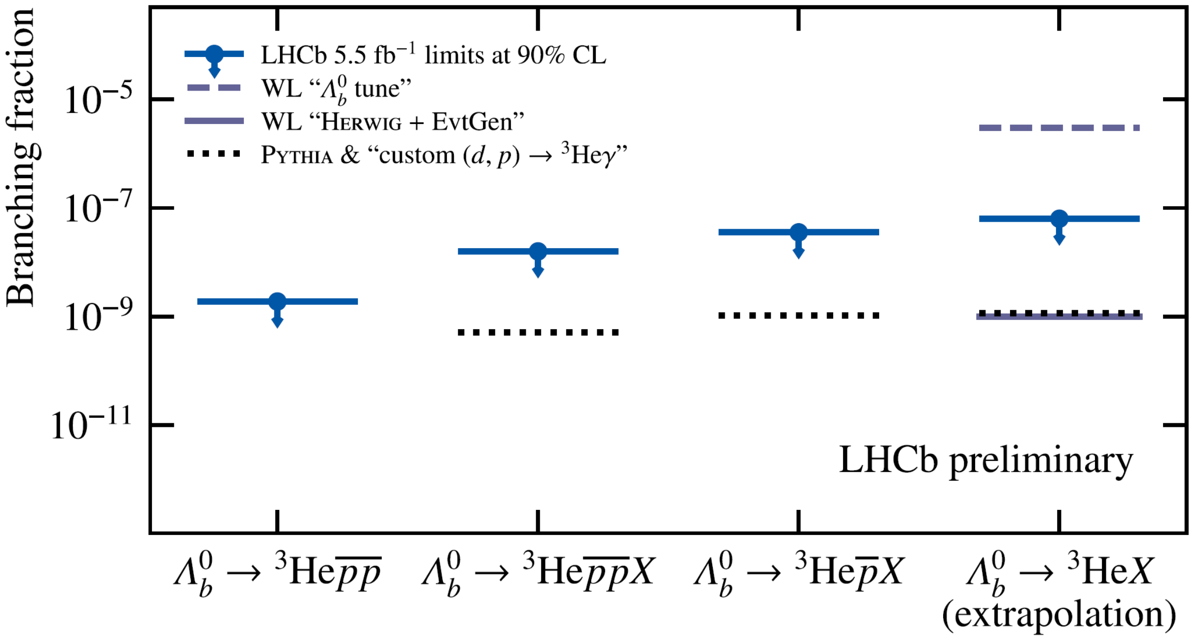
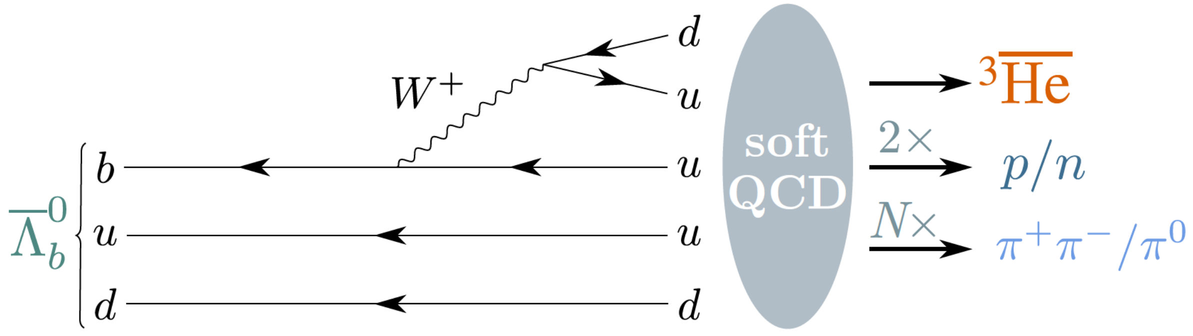


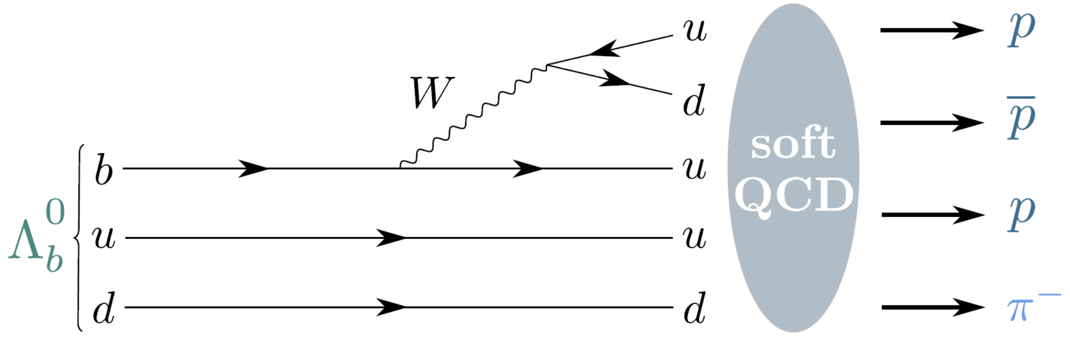
- First results on $^3\overline{\mathrm{He}}$ production in $\bar{\Lambda}_b^0$ decays
- Excluded the Λ_b^0-tune model by 2 orders of magnitude
- LHCb Run 5 & 6 potentially able to cover current estimates

Multi-baryonic Λ_b^0 decays

- Helium production in Λ_b^0 requires:
  1. 5-baryon production
  2. coalescence of 3 baryons
- Coalescence has received many attention but the 5-baryon production needs more exploration
- 5-baryon production can be studied in isolation by measuring multi-baryonic decays
- My analysis will investigate the BF of
  - $\Lambda_b^0 \to p\bar{p}p\pi^-$
  - $\Lambda_b^0 \to p\bar{p}pK^-$
  - $\Lambda_b^0 \to p\bar{p}pp\bar{p}\pi^-$

  in LHCb Run 2 & 3 data





Analysis structure

Corrected simulation & higher mass sideband as BDT training samples

Preliminary mass fits → BDT training → Background reduction and PID optimisation → Efficiency calculation

Preliminary vertex, PID cuts and mass vetoes applied

Use simulation, PIDCalib, and other data samples for optimising BDT and PID response and modelling efficiency

Control mode

$\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$

BF measurement

Validation modes

$\Lambda_b^0 \to p\pi^-\pi^+\pi^-$

$\Lambda_b^0 \to p\pi^-\pi^+\pi^-\pi^+\pi^-$

relative (to control mode) BF measurement

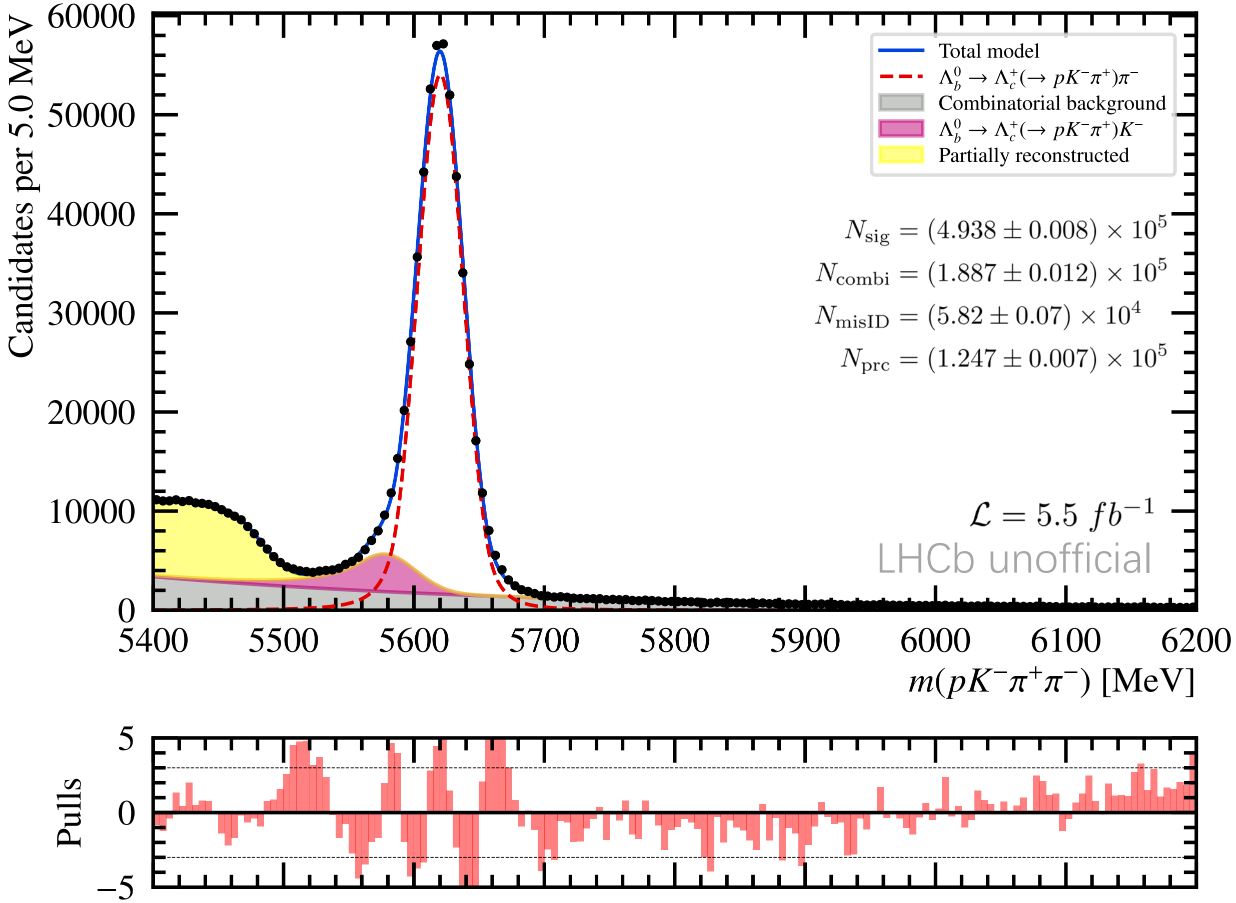
Signal modes

$\Lambda_b^0 \to p\bar{p}p\pi^-$, $\Lambda_b^0 \to p\bar{p}pK^-$

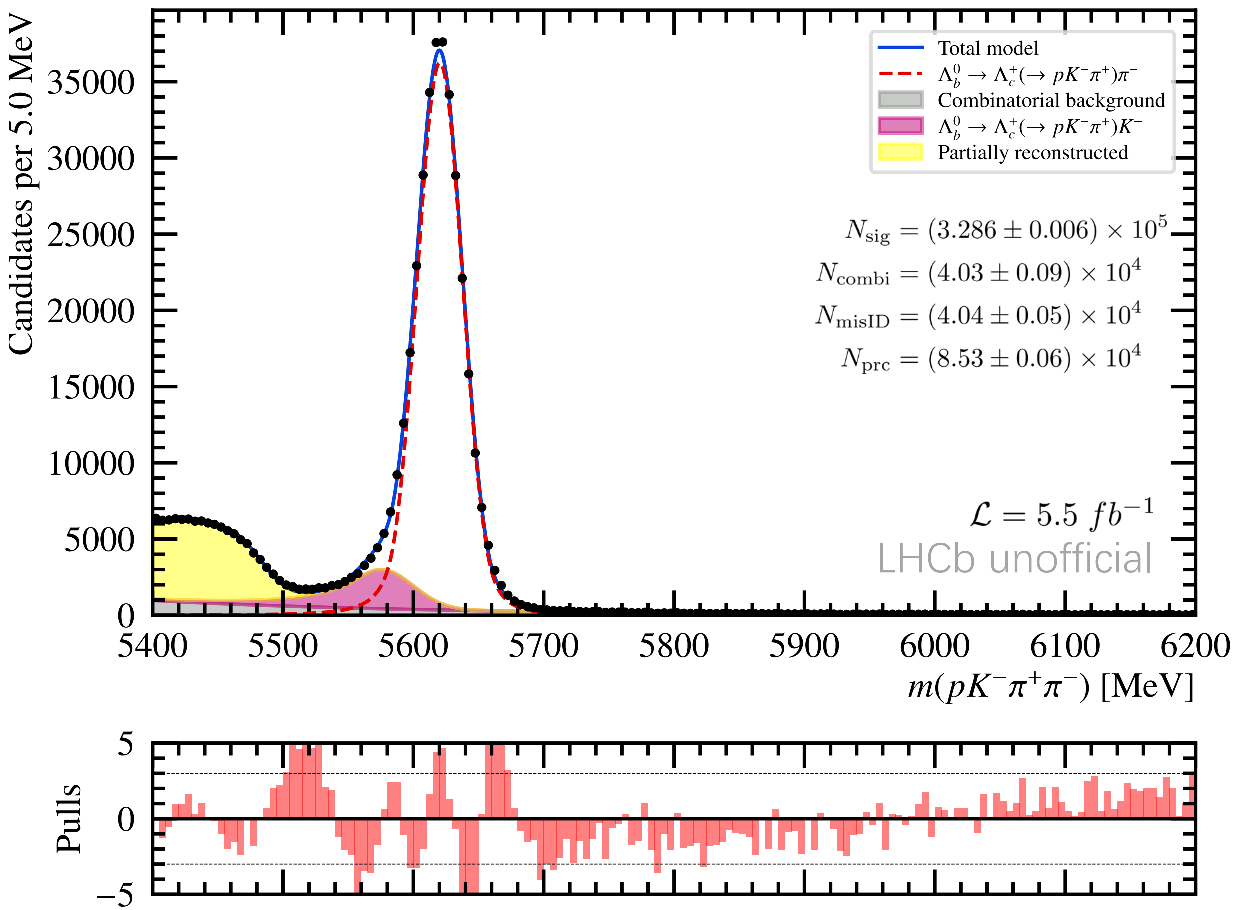
$\Lambda_b^0 \to p\bar{p}p\bar{p}p\pi^-$

relative BF measurement

Mass fits for $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ with Run 2 data

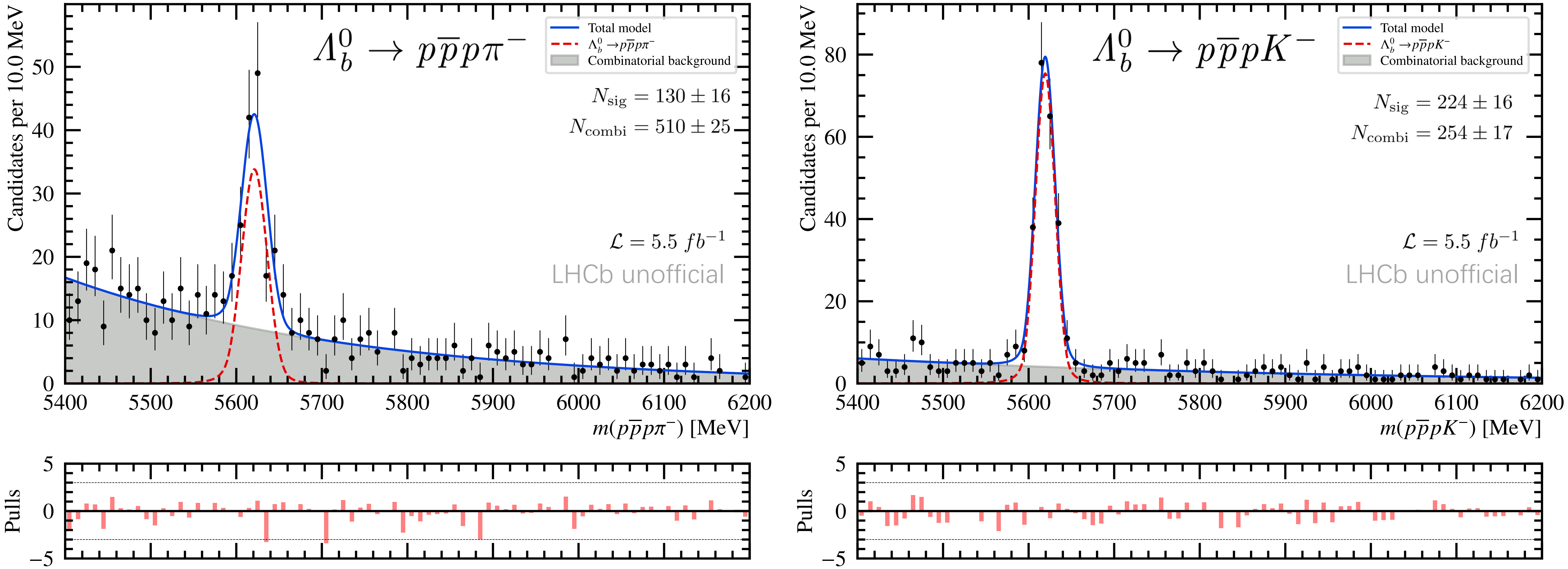


Very loose selection:
$\mathrm{ProbNN}p > 0.2$



Tight selection similar to that used for 3-proton modes:
$\mathrm{ProbNN}p > 0.9$ + extra vertex and track cuts

First observation of the decay modes $\Lambda_b^0 \to p\bar{p}p\pi^-$ and $\Lambda_b^0 \to p\bar{p}pK^-$ using LHCb Run 2 data



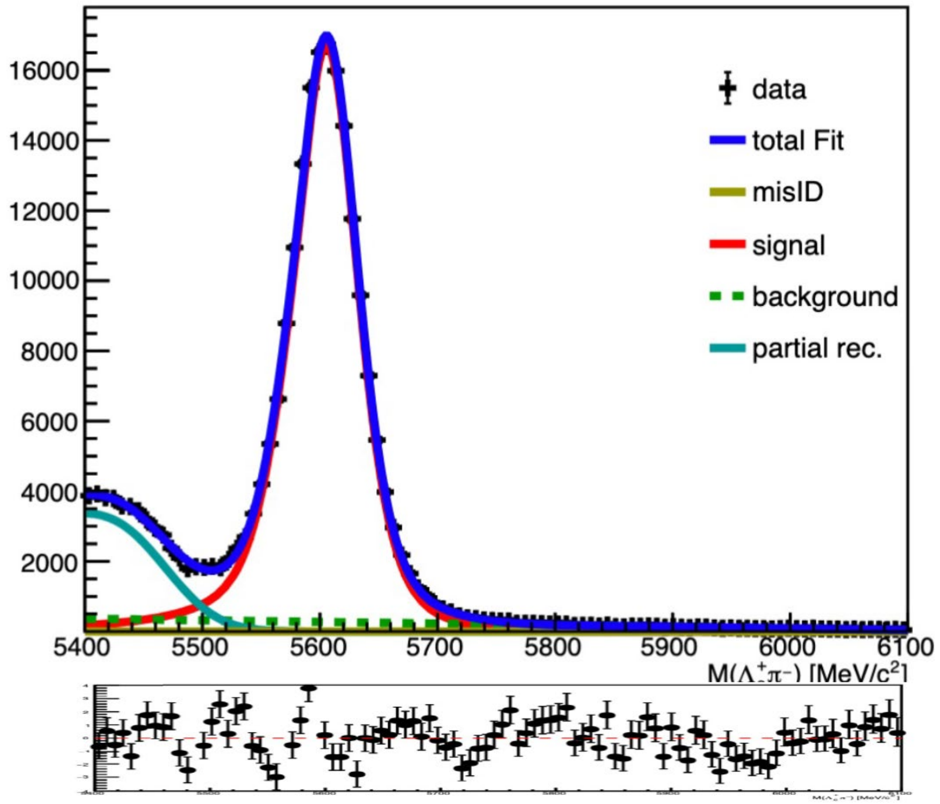
- **Above 5σ significance** for both signals
- Expect BR to be a factor of $\mathcal{O}(10)$ times smaller for the 5-proton mode

→Observation will only be possible with full Run 3 statistics

First look to Run 3 data

- Following example from XueTing Yang's analysis
- Sprucing24c1 output (up to May)
- Fill no. 9485-9708
- RunNumber: 289213-297124
- Analysis Production: bnoc_lb2p3h_sprucelines /sprucepass24c1_validation_bnoc_spruce_lbtopppippimpim
- LFN:/lhcb/LHCb/Collision24/SPRUCEPASS24C1_SPRUCE_LBTOPPPIPPIMPIM.ROOT/00226703/0000/
- Use basically same selection as for run2, except ProbNNp>0.2 → PIDp>5
- Use run2 simulation

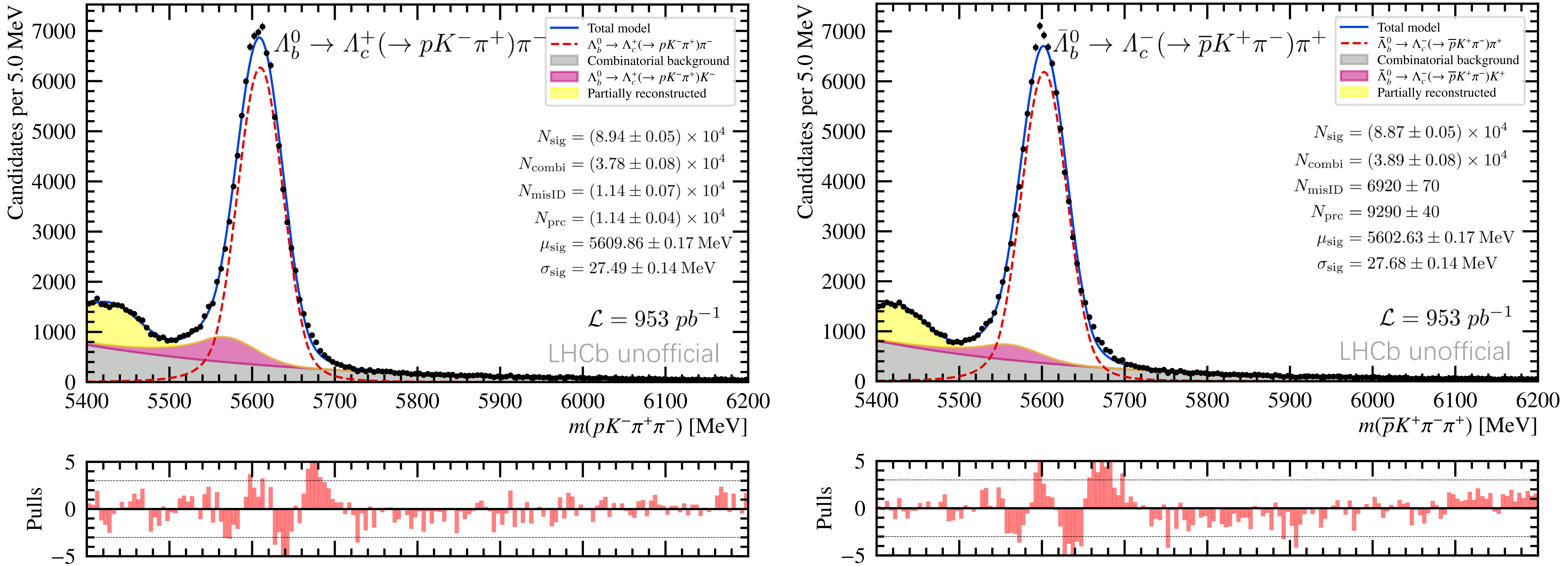
➢ Run 3



$\mu = 5605.6 \pm 0.10$ $\sigma = 36.23 \pm 0.38$

First look into 2024 data in $\Lambda_b^0 \to p3h$ decays

Mass fits for $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ with Run 3 data



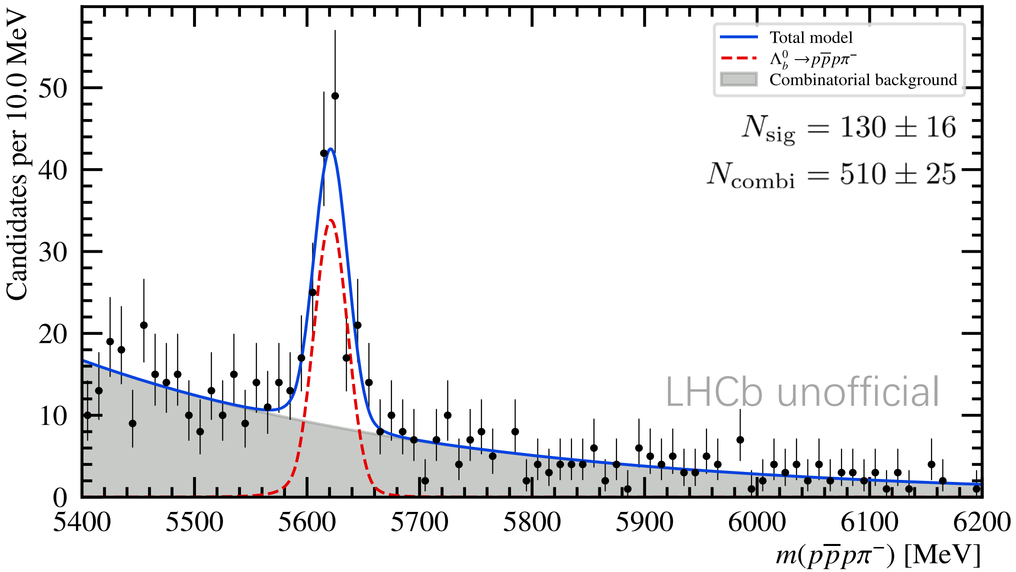
- Estimation of yield/luminosity 187 per pb^{-1} relative to 97.2 per pb^{-1} in Run 2, increase by **a factor of ~2**
- By the end of Run 3, signal yields are expected to be increase by **a factor ~12** compared to Run 2

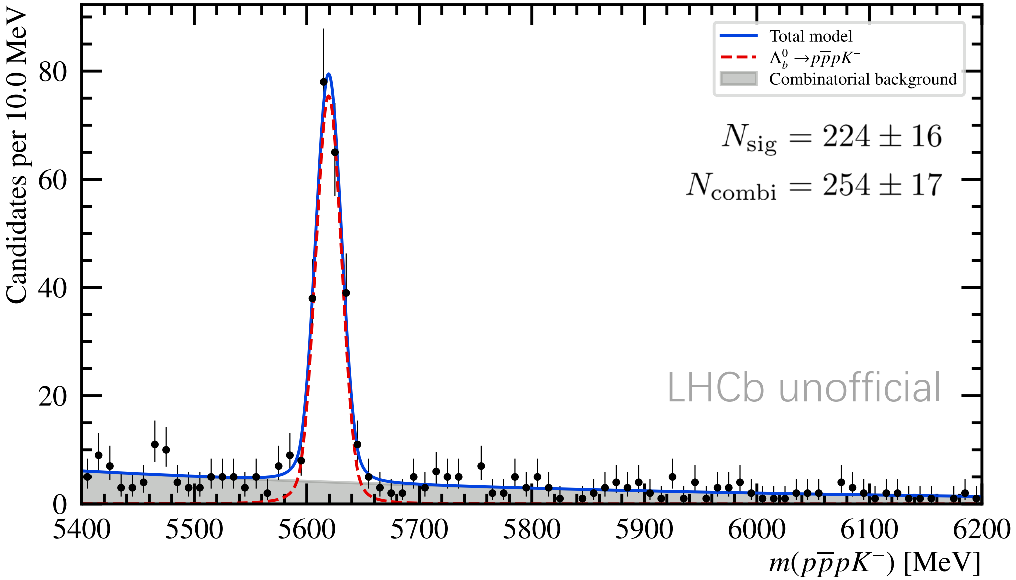
Summary

- First results for the control mode $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ and 3-proton modes $\Lambda_b^0 \to p\bar{p}p\pi^-$ and $\Lambda_b^0 \to p\bar{p}pK^-$ have been shown
- In Run 3 data, the signal yield per pb^{-1} for the mode $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ increases by a factor of ~2
- We expect $\mathcal{O}(10^3)$ Λ_b^0 decays for the 3-proton modes and $\mathcal{O}(10^2)$ decays for the 5-proton mode with the full Run 3 statistics

Next steps:

- Analysis production on sprucing 24c2 data
- Simulation request
- Validation mode fits, BDT training,..
- Target for the publication of the 3-proton modes in 2025

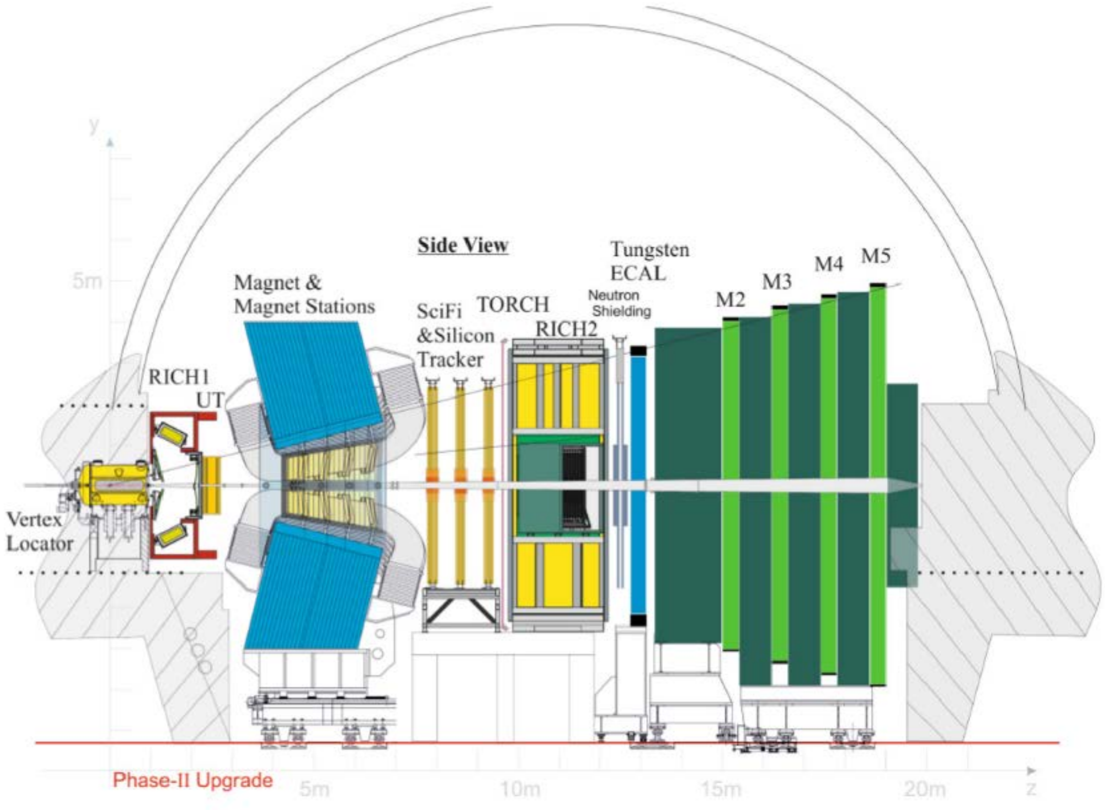




Thanks for your attention!

Appendix

D & He Identification in Run 5 & 6: Summary



Schematic side-view of the Upgrade II detector

- The combination of Mighty-SciFi, RICH and TORCH should allow to identify D, He-3 and He-4 over a wide energy range.
- In Run 2 the largest separation power comes from VELO and the dominant background are therefore photon-conversions. Mighty-SciFi and TORCH provide the measurements downstream the magnet, i.e. background from photon-conversions is here not a issue.
- The independent light nuclei identification by several sub-detectors allows to determine efficiencies from data and to cross-calibrate the PID performances.
- This opens a rich physics program relevant for QCD and astrophysics for LHCb for Run 5 & 6.

Control mode $\Lambda_b^0 \to \Lambda_c^+(\to pK^-\pi^+)\pi^-$ and validation modes $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ and $\Lambda_b^0 \to p\pi^-\pi^+\pi^-\pi^+\pi^-$

- High statistics for control mode
- Λ_c^+ easy to isolate for control mode
- BR of $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ already measured
- Same stripping line output (Xb2phhh)

⟶ Cancelation to first order of stripping efficiency in the efficiency calculation

- Similar decay topology to the 3-proton modes

⟶ Partial cancelation of systematics in proton PID efficiencies

- Same BDT

⟶ Cancelation of systematics in BDT efficiency

3-proton modes $\Lambda_b^0 \to p\bar{p}ph$ selection

Extra selection	
HLT	Hlt1TrackMVADecision_TOS or Hlt1TwoTrackMVADecision_TOS
	Hlt2Topo{2,3,or 4}BodyDecision_TOS
Vertex	$\ln(\arccos(\mathrm{DIRA})) < -5$ $\ln(\chi^2_{\mathrm{IP}}) < 2$ $\ln(\chi^2_{\mathrm{FD}}) > 4.5$ $\chi^2_{\mathrm{vtx}}/\mathrm{ndf} < 2$
Track	$p > 3\ \mathrm{GeV}$ $\mathrm{ProbNNghost} < 0.5$ $\chi^2_{\mathrm{match}} < 30$ $\chi^2_{\mathrm{track}}/\mathrm{ndf} < 3$ $!\,\mathrm{isMuon}$
proton	$\mathrm{ProbNN}p > 0.9$
Mass veto	$m(p\pi^-) > 1150\ \mathrm{MeV}$ $m(pK^-) > 1700\ \mathrm{MeV}$ $m(p\bar{p}) < 2850\ \mathrm{MeV}$

For combinatorial background reduction, to be replaced by the BDT

Preliminary, will be optimised after BDT background reduction

To reject Λ^0 resonances

To reject charmonia resonances

Outlook on Run 3 data

C. M. Benito RTA report

	Since April	> May MD	> June TS	> Aug MD	> Sept MD
Moore	v55r7p3	v55r8p1	v55r11 (v55r10p1)	v55r12p2	v55r13pX
Features	First reco and selections	New selections, ProbNN* info	UT in tracking, downstream, GhostProb retuned (r11)	New selections	New selections
Lumi [fb^{-1}]	0.22 (100%)	0.75 (100%)	4.1 (100%)	0.44 (67%)	To be collected

	post-June TS, MagUp	post-June TS, MagUp	Alignment update	post-Aug MD, MagUp
Fills	9911-9943	9945-9978	9982 - 10056	> 10059
HLT1	q/p adjustments	new BW division, no UT (0x1000106F)		new BW div with UT (0x1001075)
Alignment	N-1(after Velo belt replacement)		Latest, stable	
HLT2	Moore v55r11			Moore v55r12p2
Lumi [fb^{-1}]	0.9 (100%)	0.6 (100%)	1.2 (100%)	0.44 (67%)

- UT: better ghost tracks identification and better momentum resolution
- Alignment update: improve on the mass shift issues seen in the previous data
- The 0.44 fb^{-1} has now reached 1.9
- Expecting ~35 fb^{-1} by the end of Run 3 (2026)